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220 - 320 GHz Harmonic Mixer for a Full Band Sweep Vector Network Analyzer.

François Mattiocco, Matthew Carter, Bernard Lazareff.

Abstract **–This paper presents the design and characterization of a fixed tuned 220 - 320 GHz harmonic mixer employing commercial Schottky beam lead diodes in an antiparallel configuration. A diplexer provides distinct ports and matching for the subharmonic LO (26-40GHz) and the IF (20 MHz) . The conversion loss was measured using a Gunn + tripler or quadrupler source calibrated with an absolute bolometer. We have built a 220 - 320 GHz full band sweep Vector Network Analyzer (VNA) using two WR3 waveguide couplers and three identical harmonic mixers (transmitter, reference, and receiver) pumped by two synthesizers (13-20GHz) followed by active doublers. The available dynamic range is 60 dBc/Hz over most of the band.**

I. Introduction

The VNA is a versatile and highly sensitive instrument to test the devices and material, transmission and reflection properties in the microwave domain. Receiver fabrication for radio astronomy has involved the development of millimeter VNA which work in a frequency range up to 1THz. Above 200 GHz, the transmitter sources used in these systems are made with phase locked Gunn oscillators followed by reactive multipliers, carcinotrons [1], or harmonic resistive multipliers associated with synthesizers [2]. Gunn oscillators associated with multipliers and carcinotrons work up to 1 THz but are expensive. The Gunn phase locked band is narrow at each frequency, and the carcinotron life time is limited. The low cost resistive 220- 320 GHz harmonic multiplier or harmonic mixer we have built for the VNA can be pumped by sweep synthesizers over 40 % of the band.

II. Mixer Block

The mixer block is split in two blocks in a plane perpendicular to the input waveguide as is shown in Fig.1. The input WR3 waveguide is formed using spark erosion. Two beam lead Schottky diodes are bonded with silver loaded epoxy in an antiparallel configuration on a suspended microstrip quartz substrate (shown in Fig. 2) where the following circuits are defined: the waveguide to microstrip transition, the RF and the LO matching, the low pass rejection circuits, and the bias ground return. Input LO and output IF access are made through a K connector.

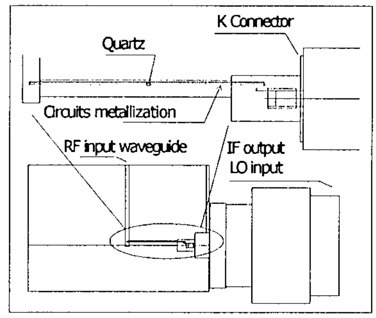

Fig. 1: Structure of the harmonic mixer bloc.

III. Mixer Design

The WR3 waveguide to microstrip transition was designed using an analytic model [3]. Figure 3 shows the real and imaginary part antenna impedance at the microstrip input as a function of the antenna length L when the antenna width w is 0.24mm and the waveguide short is at 0.34mm from the antenna. The antenna length L= 0.250mm gives an impedance real part between 45 and 50 Ohms in most of the waveguide band .

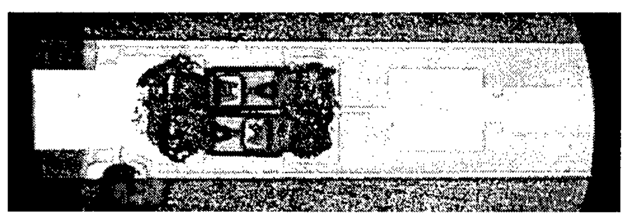

Fig. 2: Beam Lead diodes bonded on a 0.420 mm width quartz substrate of 80μm thickness.

The mixer was optimised for the best performance in the frequency range 250-300 GHz which corresponds to one of IRAM's receiver bands. The quartz substrate of 0.420 mm width was chosen to allow the integration of two diodes (0.2 x 0.15mm) and the ground return filter circuit. The first Longitudinal Section Magnetic mode (LSM) cutoff frequency given by the crystalline quartz and channel dimensions is 320 GHz [4].

Table 1: Beam lead diode specifications

Device	Cjo	CT	Rs
SBL-016	3 fF	8 fF	13 O

The matching and filtering of the RF, LO, IF and bias circuits were designed with a simple model using only the reactive and resistive impedance associated with the diode model. Table 1 shows the pair matched beam lead diode parameters [5]. The wire anode to connecting pad

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inductance Ls is 0.01 nH [6]. The differential resistance Rd which is given by the LO level was taken as a variable in the model.

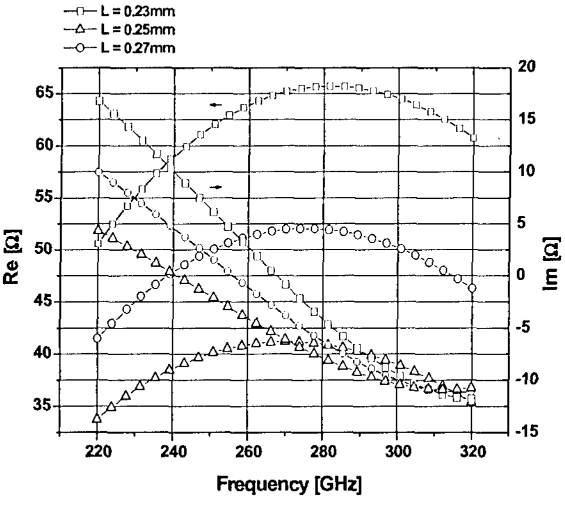


Fig. 3: Transition antenna impedance variation with the antenna length.

The RF return loss variations with the differential resistance Rd computed using the software Libra Series IV (Fig.4) are lower than -10 dB when Rd < 150 Ohms. The computation gives the RF to LO isolation of the order of 10 dB and the LO return loss stayed below -10 dB between 26 and 40 GHz.

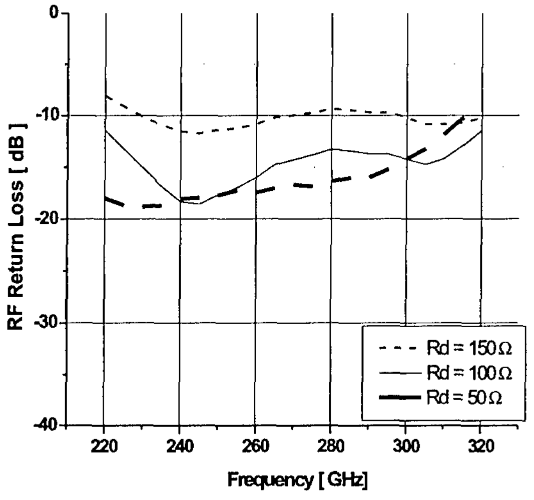


Fig.4: Computed input RF Return Loss variations with the differential resistance Rd.

IV. MIXER CHARACTERISATION

A. *Conversion Losses*

The conversion loss was measured using an association of phase locked Gunn oscillators, a tripler and a quadrupler as transceiver. The output power measured with a total power bolometer [7] and a corrugated horn at the multiplier output was of the order of -10 dBm. The local oscillator for the measured mixer is made by a 13 - 20 GHz synthesizer followed by an active doubler. The synthesizer 10 MHz internal reference was used to lock the the Gunn oscillator PLL. A diplexer provided a distinct port for the LO and the IF. The 20 MHz IF signal level was measured with a spectrum analyzer. The conversion loss given by the ratio of the 20 MHz IF output power over the RF input power using the 8^{th} LO harmonic is shown in Fig. 5. The conversion losses are between 40 and 50 dB over most of the band 220 to 320 GHz.

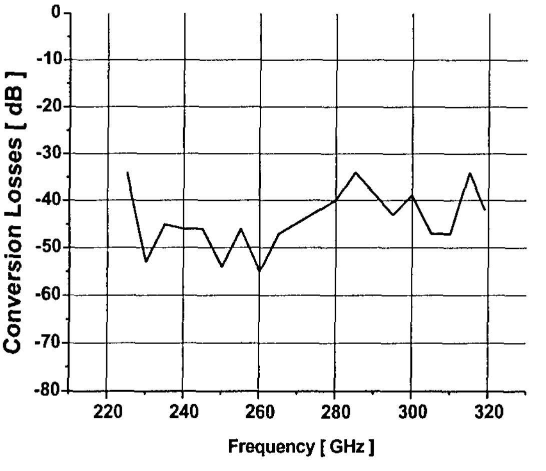


Fig. 5: Harmonic mixer conversion losses.

B. *LO Return Loss.*

The LO Return Loss measured between 26 and 40 GHz using an HP8510 VNA associated with a waveguide Test Set extension is below -7 dB between 26 and 35 GHz as shown in Fig. 6.

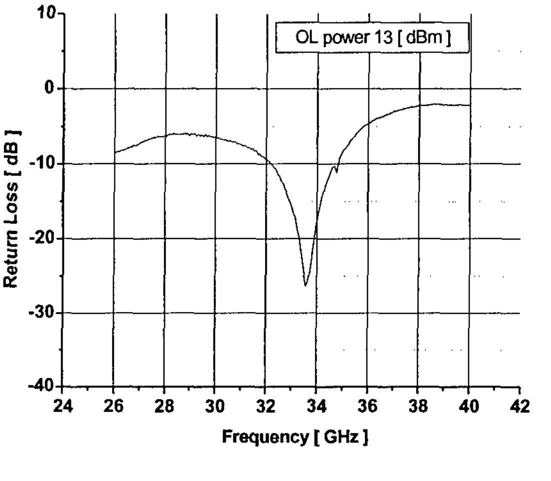


Fig.6: LO Return Loss measured with 13 dBm input signal power.

V. APPLICATION TO THE VNA

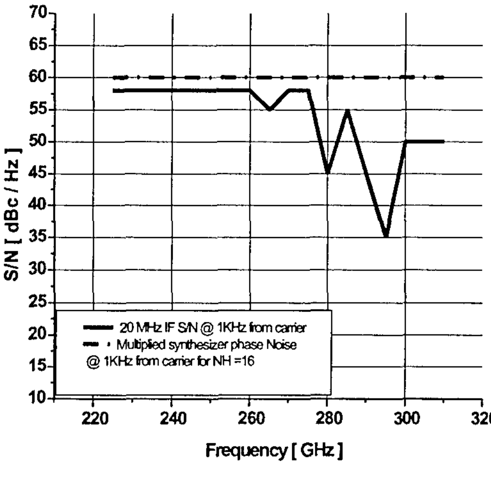
A. *VNA System*

The 220-320 GHz full band sweep VNA system is identical to the one described in the reference [2]. The performances were improved using the new WR3 harmonic mixer and the WR3 waveguide coupler. A second synthesizer was added to a 20 GHz basic HP8510

Network Analyser. The 20 MHz beat signals given by the reference, the transmission, and the reflection harmonic mixers after amplification and filtering are analysed by the HP8510 four channels 20 MHz receiver. The reference, transmission and the reflection signals were taken using two in-house made WR3 15 dB waveguide broad-wall multi-hole couplers whose reverse coupling is 35 dB. The 20 MHz IF and the 26 to 40 GHz LO are coupled to the receiver mixers via diplexers. The mixers are self-biased.

B. *IF Signal and Noise*

The 20 MHz IF signal given after emission and reception between a resistive harmonic multiplier and a harmonic mixer is observed with a spectrum analyser. The IF Signal to Noise ratio was measured after amplification at 1KHz from the carrier with a 100 Hz input filter resolution. Figure 7 shows the comparison between the 20 MHz IF S/N and the tranceiver synthesizer signal / phase noise level after multiplication by a factor of 16 and degradation of 24 dB. Below 270 GHz both are of the same order of magnitude (about 60 dBc/Hz), in this case, the phase noise is limited by the transceiver synthesiser phase noise. Above 270 GHz, the typical dynamic is 40 dBc/Hz, which is reduced below the synthesizer signal/phase noise ratio by the emission-reception conversion losses degradation. However the corresponding phase noise fluctuations stays below 1.5



degrees over the band.

Fig.7: 20 MHz IF S/N variation.

C. *Dynamic Range*

The transmission through a waveguide attenuator was measured to test the dynamic range. Figure 8 gives the transmission for three attenuation values over a dynamic of 30 dB between 220 and 320 GHz. Figure 9 gives the transmission through two attenuators over 60 dB dynamic range between 254 and 320 GHz.

D. *Calibration and typical measurement:*

The VNA is calibrated with WR3 waveguide references : short, delay-short and load. Figure 10 shows the low loss measurement of the transmission through a WR3 H-bend followed by a WR3 coupler of the same type as the one used in the VNA.

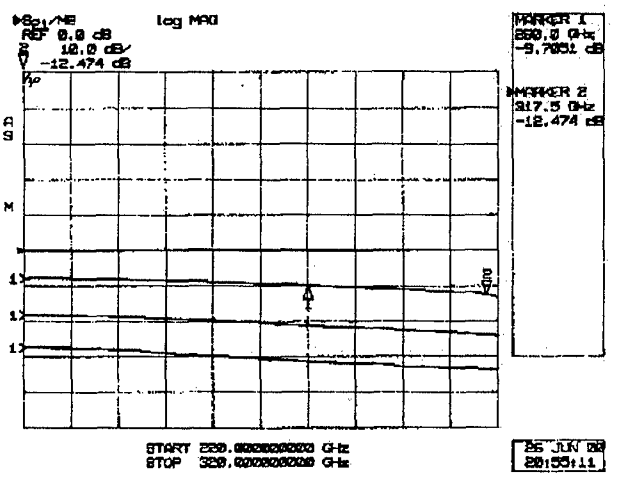


Fig.8: Transmission through one WR3 waveguide attenuator. Scale: 10 dB / Div between 220 - 320 GHz.

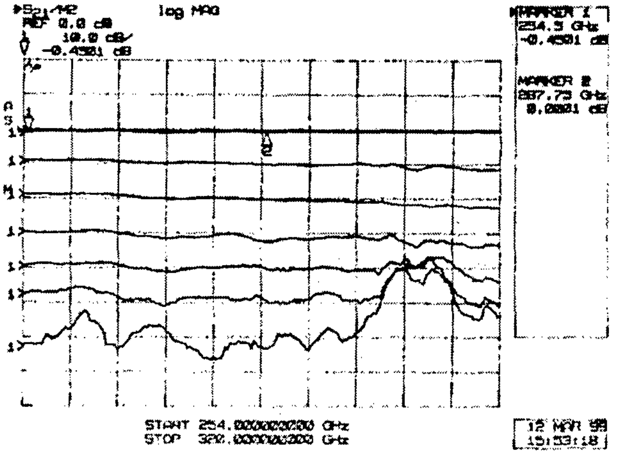


Fig.9: Transmission through two WR3 waveguide attenuators. Scale: 10 dB / Div between 254 - 320 GHz.

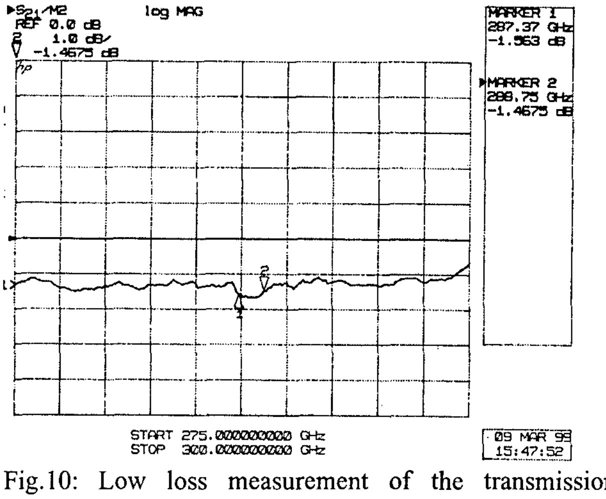


Fig.10: Low loss measurement of the transmission through a WR3 H-Bend and a WR3 coupler. Scale: 1 dB / Div between 275 to 300 GHz.

Figure 11 shows the measurement of the input reflection S11 parameter of a harmonic mixer between 220 and 260 GHz.

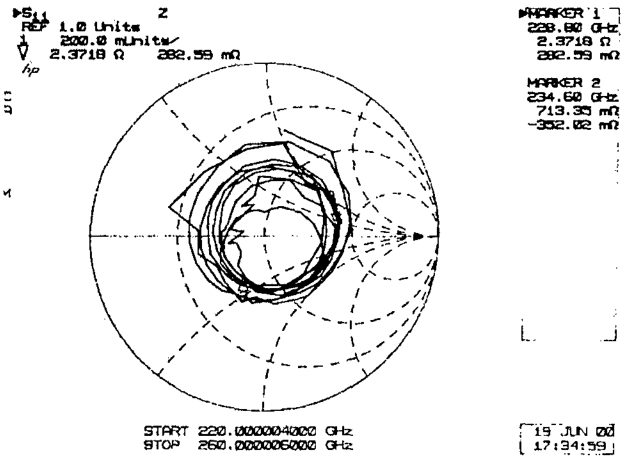


Fig.11 Input reflection S11 parameter from a harmonic mixer between 220 to 260 GHz.

VI. CONCLUSION

A 220-320 GHz fixed tuned harmonic mixer was designed built and characterised. The mixer was used to build a 220 to 320 GHz full band sweep VNA which gives 60 dB of dynamic range in a 44 seconds sweep time over most of the band. That analyser can be used to qualify a large number of devices operating in this frequency range.

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